Consolidation of Slab Penetrations Study

(Depth, Breadth-Structural)

Problem Background

The new use and construction type of Crystal Plaza II provides many unique challenges. One challenge focuses on the change from commercial to residential use. The current building will be a residential complex with approximately 266 individual rental units. This analysis is designed to evaluate the issue with slab penetrations and structural integrity issues as a result of the amount of slab penetrations. Currently the design requires nearly 300 core drilled penetrations and approximately 25 slab cuts to provide areas for the necessary risers. This process requires the use of two core drill contractors, each responsible for a different trade, coordination with curtain wall installation to avoid damage, coordination with slab leveling to avoid penetration infill, and structural preservation. The substantial amount of penetrations has caused structural issues that require a change order to the project. The change order is to install CFRP on the underside of the slabs to reinforce the slab; also a two hour fire rating is required over the reinforcement not originally included in the change order. The structural preservation process is timely, costly, and requires a large lay down area that is affecting the production on each floor for only a small amount of required reinforcing.

Problem Statement

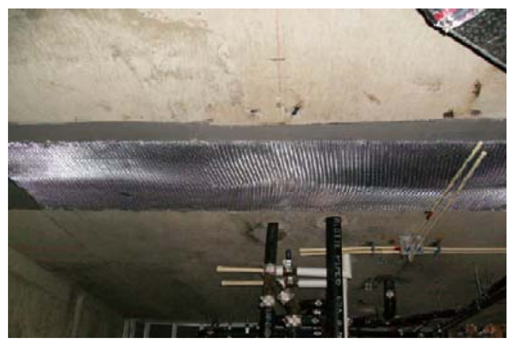

Figure 24 Fire proofed CRFP panel on underside of

The problem with the current method is in constructability, schedule, and cost. Originally, reinforcing was expected, however, was given a contingency cost with the expectations to deal with the problem as it arose on case by case basis. The original thought was that it could be identified and overcome prior to any other construction processes that may hinder the reinforcing installation. Looking in retrospect, that is not the case. Of all the areas needing reinforcing, many are marginal and would only require a few less rebar pieces to be cut. The problem is that this issue was known early in the project, but nothing was suggested to the mechanical designer or preliminary work analyzed to give an idea of what may need to be done. Rather, a do first, check second approach was taken. This approach often leads to costly change orders and schedule increases. Luckily on this project the construction was ahead of schedule enough to absorb the additional time, however the rework of installed material and cost for the reinforcing came at a premium. While this analysis will not cover mechanical/plumbing design, the information provided could aide in that process and influence the decision as to riser sizes, locations, and possible consolidation of risers. If done correctly, minimal increase in risers could allow for no use of the costly reinforcement.

Goals

The goal of this analysis is to locate the marginal areas requiring reinforcing, as well as provide a structural analysis that could have been implemented during preconstruction to mitigate the risk associated with the structural reinforcement. Concern for the MEP system will be addressed in terms of reconfiguration, but no calculations will be necessary. The idea is to provide a method to identify potential problem areas and marginal areas. In terms of problem areas, the issue can be assessed in a timelier manner after the evaluation and additional systems can postpone installation until the CFRP is in place. For the marginal areas, slight adjustments by the MEP designers could potential save the need for the reinforcing all together.

Research Procedure

1. Conduct interview with Mechanical/Plumbing designer
2. Select risers to be consolidated for typical floor
3. Determine new penetrations per typical floor
4. Conduct interview with Structural designer and obtain reinforcement calculation
5. Identify problematic areas that may require structural reinforcement
6. Evaluate need for structural reinforcement
7. Re-evaluate system if necessary to avoid structural reinforcement
8. Estimate cost and schedule impact of new layout
9. Compare new cost/schedule to existing to determine advantages/disadvantages

Tools and Resources

1. GHT Limited (MEP Designer)
2. Tadjer Cohen (Structural Engineer)
3. RS Means 2008
4. Mechanical & Electrical Equipment for Buildings by Stein and Reynolds
5. MS Project or Primavera Project Manager

Expected Outcome

The expected outcome of this analysis is that with the consolidation of applicable risers, the amount of slab penetrations can be reduced by a number that allows for no additional structural reinforcement. Given the limited number of areas requiring reinforcing, it is expected that by eliminating only a select few penetrations or moving select slab openings, the use of structural reinforcing can be avoided

Research Background

This analysis is focused on the constructability of the structural reinforcement at Crystal Plaza II. Reinforcement becomes necessary as the building use changes, therefore altering loading conditions and the need for more slab penetrations. The original structure was designed as commercial office use with a 100 psf live load condition. The new residential use allows for much lower loading conditions, 40 psf live load and 10psf dead load for partitions. However, given the need to create slab penetrations, some rebar will be cut, therefore eliminating its reinforcement ability. This is due to the reconfiguration of the space, which when reviewing a graphic presented earlier, shows the vast increase in slab penetrations. For instance, each new bathroom will have 3-9 new penetrations, and with these areas located next to each other, the result is often 6-12 penetrations in a relatively small area. The problem arises when too much rebar is cut and there is a need for exterior reinforcement using other means, in this case carbon fiber reinforced polymer.

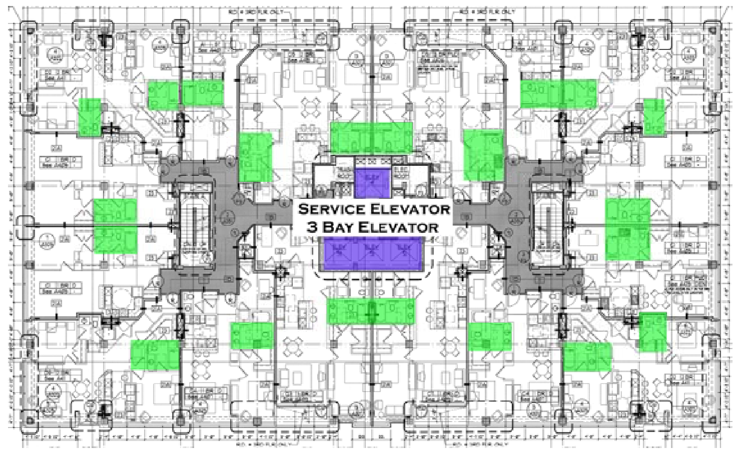

Figure 25 New floor layout with elevators in blue and bathrooms in green

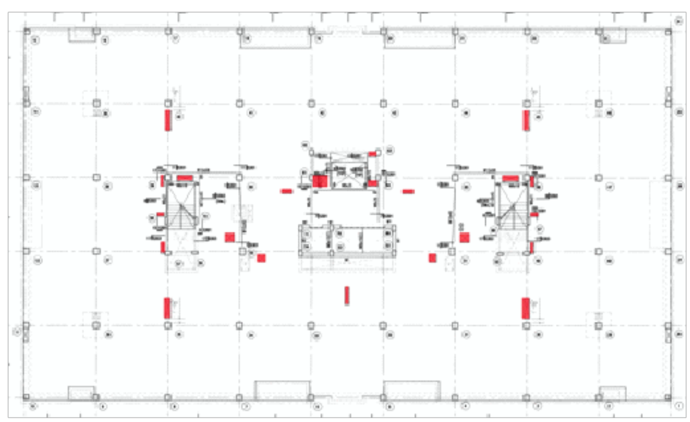

Figure 26 New slab cut locations for duct shafts only

As construction proceeded it was impossible to avoid cutting more than the minimal amount of rebar. Even with the existing drawings, the exact location of the rebar could not be found given the way that it is installed. Use of ground penetrating radar (GPR) would be necessary to locate the rebar, and even then it is not as accurate as would be expected for the cost inquired. Therefore it seems that overall there is no way of knowing how much rebar will be cut until it is actually cut. While this is correct, it is this analysis's goal to determine what areas are critical, in that if a single bar is cut, reinforcement will be needed, and those that can be avoided, in that multiple bars can be cut. In the later circumstance it would make sense to identify these areas during preconstruction and provide the information to the mechanical/plumbing designer. While the layout of the mechanical/plumbing system is somewhat fixed by the location of walls, duct shafts, and necessary area for slopes, some changes may be made to lower the amount of penetrations, such as a slab cut in an area with a low density of rebar rather than multiple cores through a high density area. While slight modifications would ensue, the cost of changes to the mechanical/plumbing system in terms of additional materials due to a less than ideally efficient design would be offset by the savings associated with the cost of reinforcing.

At Crystal Plaza II, little consideration was given the structural strength, and therefore in the do first, check second ideology, numerous areas of reinforcement were required. To add to the situation, a member of the construction team would need to identify, using each individual core, the amount, location (top or bottom), and the direction of the cut rebar. This task in itself was nearly a full time job, as nearly 4,000 cores would need logged and represented on a drawing for the structural engineer to evaluate the integrity of the slab.

Once the engineer had the data, a software program evaluated the structure in much the same way that will be illustrated later, but on a much more detailed level. The program compared the required reinforcing for the new occupancy load to the amount of rebar left after cuts and determined if reinforcement was needed. The engineer paid special attention to certain areas where the design was dictated by requirements outside of strength or flexure. One instance was in the middle strip where design is often dictated by shrinkage and temperature requirements. Also noted was if a bottom bar was cut close to a support (typically where top rebar governs) if it was still able to perform at the center in terms of resisting the maximum moment, which would mean that it was still doing its job and no reinforcement would be needed.

Now, because the project has progressed since the procedure has been underway, the reinforcement crew would need to mobilize and begin work. This became the area of concern and ideally where the problem can be resolved. Due to the progress, many systems had been installed that would now require rework to allow the crew to install the carbon fiber reinforced polymer. This creates stress and interrupts work flow for all the trades involved. Of even more concern was the overlook of the design and managing parties of the requirements for fire proofing that would ultimately lead to more and costlier rework, as well as close in inspection postponement.

It seems that during the preconstruction period some system should have been implemented to mitigate this risk. The idea proposed later in this section is one way that could have potentially allowed the general contractor to see the outcome of the slab penetrations and therefore address them well before construction. This would be a check first, do, then evaluate.

Materials

Figure 27 A roll of CFRP (top), CFRP installation (bottom)

The material used in this project is carbon fiber reinforced polymer (CFRP). The material has many applications outside of the construction world including automobiles, high end sports equipment, and in the aerospace industry. The primary reason is the materials high strength and light weight. However, its use in the construction industry is primarily structural and is cost effective in strengthening concrete, masonry, steel, and other structural members.(Carbon Fiber Reinforced Polymer, 2009) Although CFRP can be used as an alternative to steel in reinforcing, its primary use is in renovations, as is the case at Crystal Plaza II.

Typically applied to concrete structures, the CFRP reinforces the column or slab for flexure. The added strength can sometimes exceed twice the strength of the unreinforced section, however, only small gains are made in stiffness. CFRP has an ultimate tensile strength along the lines of 3,000 MPa, but very little stiffness. This being the case, only small cross sections is used for reinforcing and largely focus on adding strength.(Carbon Fiber Reinforced Polymer, 2009)

In terms of columns, the added CFRP improves the shear strength and can affect the section ductility positively as well. This is extremely important in seismic zones as it is a common retrofit to structures given its relatively low cost.(Carbon Fiber Reinforced Polymer, 2009)

Constructability

The main focus of this analysis is the constructability of the project. With the do first check, second approach to core drilling and slab cutting, many problems arose on the project. Fortunately, these problems only created headaches and had little effect on the budget or the schedule. Each of these areas is discussed in more detail with actual results from the project and the implementation of CFRP as reinforcement.

Schedule

With the phased occupancy of Crystal Plaza II and the advanced lease of the units by the owner, there is little room for schedule increase. This being the case, time must be regained in one of two ways, adding capacity or adding time (overtime). It is always in best interest to avoid both if possible as both situations incur large costs. However, the installation of the CFRP process's effect on the schedule was able to be mitigated in a way that is unique to the renovation style of construction.

Figure 28 Typical installed material requiring

As stated earlier, much of the area requiring the CFRP is already complete in terms of rough in of the primary systems (mechanical, plumbing, framing). This requires the installed material to be removed by the subcontractor responsible, stored during the installation process of the CFRP, and then reinstalled, essentially doing the work twice. Not only does this impact the schedule, but the quality of work and product as it runs the risk of damage during removal and reinstallation. Luckily the installation process was started prior to the close in of the walls, requiring no drywall to be removed and little framing.

Figure 29 Installation of CFRP

The installation process for CFRP requires a large lay down area and somewhat dangerous chemicals to adhere the carbon fiber to the slab. Initially the slab was cleaned and prepped for the installation; the CFRP was then applied, allowed to dry, and then covered with a protective resin. This process takes anywhere from 2-7 days per floor and requires the work on the floor of other trades to basically stop. The ability for the trades to work on other floors, such as above or below, allows the project to stay on schedule overall, but adds about a 3 week delay to any given floor as the CFRP process is completed. However, since the project was proceeding ahead of schedule, there are no problems with this delay as it becomes even less on the upper floors where fewer strips of CFRP are needed.

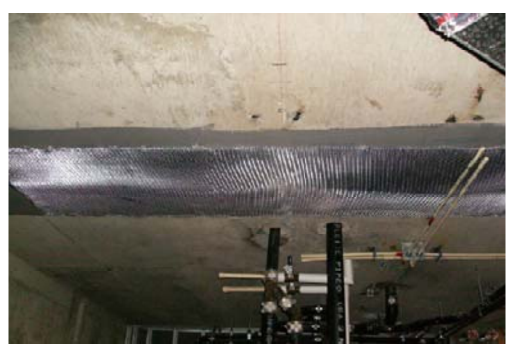

Figure 30 Installed CFRP with 2 hour fire proofing

The next issue with the schedule occurred when the overlooked task of fireproofing was noticed. The requirement did not arise until after drywall had been installed on the lower floors. To further complicate the situation, local inspectors would not continue close in inspections until the issue was resolved. This caused the drywall schedule to be extended by 2 weeks, however, not being on the critical path, did little to the overall project schedule.

While the current schedule allowed for these changes, the potential was recognized to create a significant setback with large consequences. By implementing a preconstruction review of this situation, the ability to stay ahead of schedule would be available, thus allowing time for more critical issues to be resolved. While the drywall was not on the critical path, the potential to save 2 weeks on the lower floor could allow turnover to be advanced, and the tenants to occupy the building sooner. Also, the extra time would be useful during the occupancy inspections if a problem is identified. It seems that by identifying the problematic areas, attempting to limit the amount of rebar cut, and locating potential areas of reinforcement, up to 5 weeks could be saved.

Cost

The area of cost was the largest issue when dealing with the CFRP. In total nearly $120,000 worth of extra work was required to successfully reinforce and fire proof the structure. While this is a small percentage of the overall project cost, not nearly as much was allowed for the CFRP in the budget.

The initial reinforcement of all slabs totals 840 sf (420 lf of 2 foot wide strips), and is placed in various amounts, with various lengths on each floor. The most problematic floors are from 3-7, with the 3rd floor receiving nine strips of CFRP. The cost for the 840 sf of CFRP is about $42,000, or $50 per square foot of CFRP. The cost to survey the areas and rework the installed materials was over $30,000. This cost does not include costs to the contractor in the review of the cores and slab cuts to locate the cut rebar. This time not only cost the contractor an employee for nearly 8 weeks, but also cost about $8,000, as the employee worked nearly full time on this aspect.

The area that was not anticipated, spray fireproofing, cost the contractor about $50,000 total, $21,000 for the spray fireproofing and $25,000 for the rework. Rework included removing installed drywall on the lower floors and basic mechanical/plumbing distribution on upper floors.

Proposed Preconstruction Structural Analysis

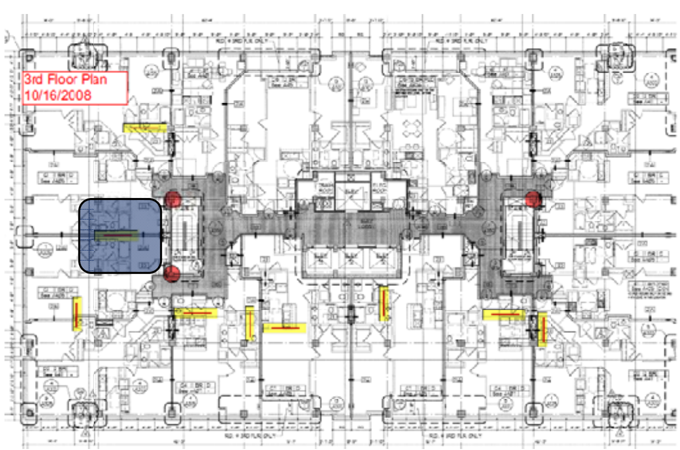

Figure 31 3rd floor plan showing reinforcing for soffit of 4th floor, area for analysis shown in blue

The proposed preconstruction analysis will look at a single frame that includes the need for reinforcement on the 3rd floor. This area is common for reinforcement through many of the floors including floors 2, 3, 4, and 5. The analysis could be easily expanded to look at additional frames to evaluate the situation in that given location. The issue with this analysis is that if done in preconstruction, the areas of interest may not yet be known, and a full slab analysis would be required. While this is not out of the question, it could be timely. For reference, floor plans of floors2-11 are included in Appendix B. Please note that the reinforcing shown would be on the slab soffit of the above floor, in other words, the reinforcing shown on the 2nd floor plan would be placed on the 3rd floor slab soffit.

To evaluate the areas of concern, a spreadsheet was used that allows for calculation of required rebar given loading conditions, column sizes, slab thickness, and bay size. The spreadsheet calculates the moments of the frame using this information and then provides a number of bars of the selected diameter required according to code. The spreadsheet is a tool that uses the direct design method (DDM) and will be used to analyze the existing use of the building as a base line, then again for the new use. The difference in the number of bars for a particular frame shows potentially how many bars could be cut in both the column and middle strips.

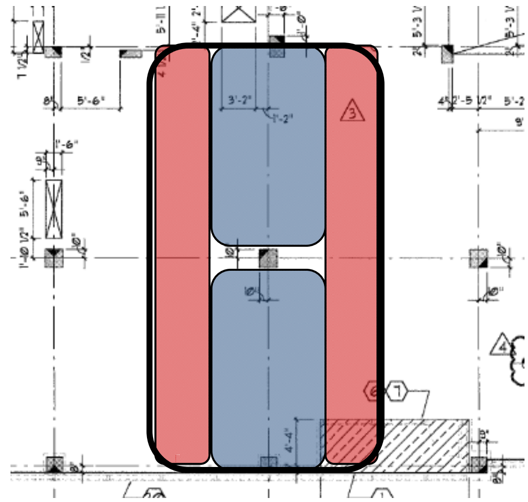

Figure 32 Typical frame with column strip in blue and middle strip in red

Existing Building Use Analysis

This analysis will serve as the base case to compare the new use to. Basically the number of rebar found in the calculation of the spreadsheet will be compared to the as built drawings from the original construction. While code and over design amounts have changed over time, the number of bars needed by the calculation should closely reflect the amount of bars shown on the drawing. This is a first check of the spreadsheet. These values will then be changed to show the new building use with a lower loading. The resulting number of rebar will then be compared to the base case, thus allowing a rough determination of the amount of bars that can be removed (cut), for the slab to remain adequately designed.

The area chosen for analysis is show above and in greater detail below. This area is marked as a marginal area for reinforcement, meaning that in most instances if one less bar would be cut, the area would not need reinforcement.

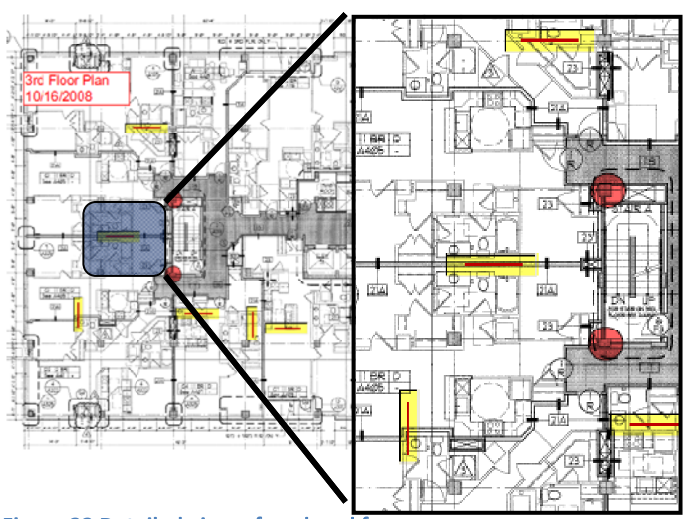

Figure 33 Detailed view of analyzed frame

The existing structure was designed for a 100 psf live load, with 20' x 20' bays, and 20" x 20" columns. It has been assumed that 5000 psi concrete was used, as is the case on the upper, new floors. From the existing drawings, the common bar size is #4 with a diameter of 0.5 inches and an area of 0.2 in^2. This information is entered into the spreadsheet as follows:

l_1 (ft)	20		ϕ_{bar} (in)	0.5
l_2 (ft)	20		d(in)	7.975
t_{slab} (in)	10		A_{bar}	0.2
γ_c (pcf)	150			
f'_c (psi)	5000			
f_y (psi)	60000			
Column Size	20	in		
	20	in		
w_{SDL} (psf)	0			
w_{DL} (psf)	125			
w_{LL} (psf)	100			
wu (psf)	310			

l_1 and l_2 are the length of the bays (20 ft)
t_{slab} is the slab thickness
γ_c is the density of the concrete
f'_c is the strength of the concrete
f_y is the yield strength of the steel
w_x represents various loads, DL (deal load), LL (live load), etc.
ϕ_{bar} is the diameter of the selected bar
d is the bar depth in the slab
A_{bar} is the bar cross sectional area

The spreadsheet uses the values inserted into the pink cells to calculate positive and negative moments in 4 frames.

Frame A: North South frame that is not an end frame
Frame B: North South frame that is an end frame
Frame C: East West frame that is not an end frame
Frame D: East West frame that is an end frame

For this analysis only frames A and C are needed and because of the bay layout are identical.

The following frame moments are results of the input.

Frame Moments				
Frame	A	B	C	D
M_o (ft-Kip)	260.49	130.24	260.49	130.24
Positive & Negative Moments	-182.34	-33.86	-182.34	-33.86
	135.45	67.73	135.45	67.73
	-182.34	-91.17	-182.34	-91.17

These values are then applied to the middle and column strips for the following summary with the frames investigated highlighted.

Frame	Total Width (ft)	CS (ft)	MS (ft)	Total - Moment	CS (-M)	MS (-M)	Total + Moment	CS (+M)	MS (+M)
A	20	10	10	-182.34	-136.76	-45.59	135.45	81.27	54.18
B	10	5	5	-33.86	-33.86	0.00	67.73	40.64	27.09
				-91.17	-68.38	-22.79			
C	20	10	10	-182.34	-136.76	-45.59	135.45	81.27	54.18
D	10	5	5	-33.86	-33.86	0.00	67.73	40.64	27.09
				-91.17	-68.38	-22.79			

These values are then applied to the following chart showing the maximum negative and positive moment in the column strip (CS) and middle strip (MS). The nominal moment is calculated in line 4. Line 6 requires data from table A.5a in The Concrete Design for Structures guide. Line 7 provides the area of steel. The area of steel required (line 7) is then compared to the minimum for shrinkage and temperature, and using the greater in line 9, the number of required bars is determined.

For Frame A Design Reinforcement For CS (Will Use #4 Bars)			
Item	Description	Span	
		M^-	M^+
1	M_u (ft-Kip)	-136.76	81.27
2	b (in)	100	100
3	d(in)	7.975	7.975
4	$M_n = M_u/0.9$ (ft-Kip)	-151.95	90.30185
5	$R = M_n/bd^2$	286.6957	170.3792
6	ρ [Table A.5a]	0.005	0.0028
7	Ast = ρbd (in^2)	3.9875	2.233
8	$A_{st,min}$ = 0.002bt	2	2
9	N = #7 or #8 (Greater)/Abar	**19.9375**	**11.165**
10	Nmin = $width_{strip}/2t$	**6**	**6**
*** # Bars used is greater value of 9 or 10**			

For Frame A Design Reinforcement For MS (Will Use #4 Bars)			
Item	Description	Span	
		M^-	M^+
1	M_u (ft-Kip)	-45.59	54.18
2	b (in)	100	100
3	d(in)	7.975	7.975
4	$M_n = M_u/0.9$ (ft-Kip)	-50.6501	60.20123
5	$R = M_n/bd^2$	95.56524	113.5861
6	ρ [Table A.5a]	0.0016	0.0019
7	Ast = ρbd (in^2)	1.276	1.51525
8	$A_{st,min} = 0.002bt$	2	2
9	N = #7 or #8 (Greater)/Abar	**6.38**	**7.57625**
10	Nmin = $width_{strip}/2t$	**6**	**6**
*** # Bars used is greater value of 9 or 10**			

From these tables, the following values are of note. In the column strip, 20 bars are needed in each direction to resist the loads, and 8 bars in the middles strip. When compared with the existing drawings, shown below for the area, it can be seen that there are approximately 12 bars in the column strip going north south, and approximately 14 bars going east west. The value for the column strips is higher than used in the drawing, however, given changes in code the values are ok. In the middle strip there are 9 bars shown on the existing drawing in each direction, which is greater than the amount found in the spreadsheet.

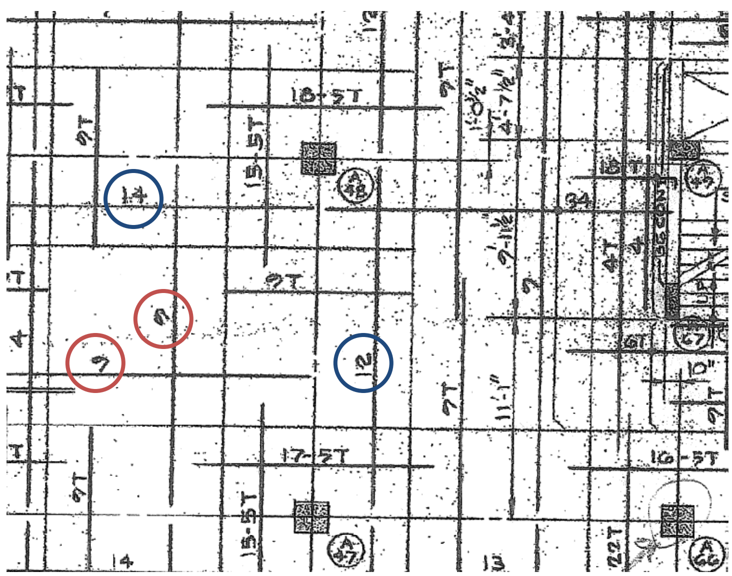

Figure 34 Existing rebar drawing, blue circled rebar is in column strip, red circled rebar is in middle strip

New Building Use Analysis

For the new building use, much of the system stays the same. The only difference is the load applied to the structure since it is now a residential use. For this the structural engineer used a live load of 40 psf and a dead load for partitions of 10 psf. The spreadsheet was completed again using the same size rebar, #4, to compare the amount of reinforcing required. The value should be less, and therefore the difference between the two rebar values will show the amount of rebar that is able to be cut. As an additional comparison, the new rebar value will be compared to the existing drawings, since the value for rebar varies slightly. This will give a range of values that can then be applied to the area to see how much rebar can be cut. This information could be vital in the layout of risers and shafts as the ability to limit the amount of rebar cut is now known information. However, the field evaluation would still be required to identify the exact amount of rebar cut. Special attention will need to be paid when the same piece of rebar is cut. This should not count as cutting 2 rebar as it is a single bar that has been cut multiple times, therefore only reducing the bar count by one.

The following is the input for the spreadsheet:

l_1 (ft)	20		ϕ_{bar} (in)	0.5
l_2 (ft)	20		d(in)	7.975
t_{slab} (in)	10		A_{bar}	0.2
γ_c (pcf)	150			
f'_c (psi)	5000			
f_y (psi)	60000			
Column Size	20	in		
	20	in		
w_{SDL} (psf)	10			
w_{DL} (psf)	125			
w_{LL} (psf)	40			
wu (psf)	226			

The following is the frame moments results for the above inputs:

Frame Moments				
Frame	A	B	C	D
M_o (ft-Kip)	189.90	94.95	189.90	94.95
Positive & Negative Moments	-132.93	-24.69	-132.93	-24.69
	98.75	49.37	98.75	49.37
	-132.93	-66.47	-132.93	-66.47

These values are then applied to the middle and column strips for the following summary with the frames investigated highlighted.

Frame	Total Width (ft)	CS (ft)	MS (ft)	Total - Moment	CS (-M)	MS (-M)	Total + Moment	CS (+M)	MS (+M)
A	20	10	10	-132.93	-99.70	-33.23	98.75	59.25	39.50
B	10	5	5	-24.69	-24.69	0.00	49.37	29.62	19.75
				-66.47	-49.85	-16.62			
C	20	10	10	-132.93	-99.70	-33.23	98.75	59.25	39.50
D	10	5	5	-24.69	-24.69	0.00	49.37	29.62	19.75
				-66.47	-49.85	-16.62			

These values are then applied to the following chart showing the maximum negative and positive moment in the column strip (CS) and middle strip (MS). The nominal moment is calculated in line 4. Line 6 requires data from table A.5a in The Concrete Design for Structures guide. Line 7 provides the area of steel. The area of steel required (line 7) is then compared to the min for shrinkage and temperature, and using the greater in line 9, the number of required bars is determined.

For Frame A Design Reinforcement For CS (Will Use #4 Bars)			
Item	Description	Span	
		M^-	M^+
1	M_u (ft-Kip)	-99.70	59.25
2	b (in)	100	100
3	d(in)	7.975	7.975
4	$M_n = M_u/0.9$ (ft-Kip)	-110.777	65.83296
5	$R = M_n/bd^2$	209.0104	124.2119
6	ρ [Table A.5a]	0.0036	0.0021
7	Ast = ρbd (in^2)	2.871	1.67475
8	$A_{st,min} = 0.002bt$	2	2
9	N = #7 or #8 (Greater)/Abar	**14.355**	**8.37375**
10	Nmin = $width_{strip}/2t$	**6**	**6**
*** # Bars used is greater value of 9 or 10**			

For Frame A Design Reinforcement For MS (Will Use #4 Bars)				
Item	Description	Span		
		M^-	M^+	
1	M_u (ft-Kip)	-33.23	39.50	
2	b (in)	100	100	
3	d(in)	7.975	7.975	
4	$M_n = M_u/0.9$ (ft-Kip)	-36.9255	43.88864	
5	$R = M_n/bd^2$	69.67015	82.80794	
6	ρ [Table A.5a]	0.0012	0.0014	
7	Ast = ρbd (in^2)	0.957	1.1165	
8	$A_{st,min}$ = 0.002bt	2	2	
9	N = #7 or #8 (Greater)/Abar	**4.785**	**5.5825**	
10	Nmin = $width_{strip}$/2t	**6**	**6**	
*** # Bars used is greater value of 9 or 10**				

From these charts, the new rebar requirement can be seen. Since frames A and C are identical, there is no need to show the results for frame C. The required rebar in the middle strip going in both directions is 6 bars, while in the column strips it is 15 bars. These values are lower than that calculated earlier, as was expected with the lower loading factors.

Comparison

The chart below compares the two analyses to find the number of bars that can be removed without endangering the structural integrity of the slab. Negative numbers indicate that even without cutting, reinforcement would be needed. This is hard to believe given the reduction in load, but only occurs when using the drawings. A primary reason could be that in the column strip near the supports the upper bars begin to control, rather than the lower bars which the spreadsheet analyzes. However, using the values from the charts yields positive results. This information could be passed along to the MEP designer thus allowing them to better place the risers and shafts to avoid structural issues. Even so, the ability to maneuver the risers is difficult given the limited space allowed in riser areas and wall locations that house the risers.

Frame Type	Direction	Strip	Bars Required Existing	Bars Required New	Bars from Existing Drawing	# Bars Removable	
						From Charts	From Drawing
A	NS	Column	20	15	12	5	-3
A	NS	Middle	8	6	9	2	3
C	EW	Column	20	15	14	5	-1
C	EW	Middle	8	6	9	2	3

This information could be extremely helpful, especially in the following areas deemed marginal by the structural engineer, meaning that reduction by 1 bar cut could mean no reinforcement.

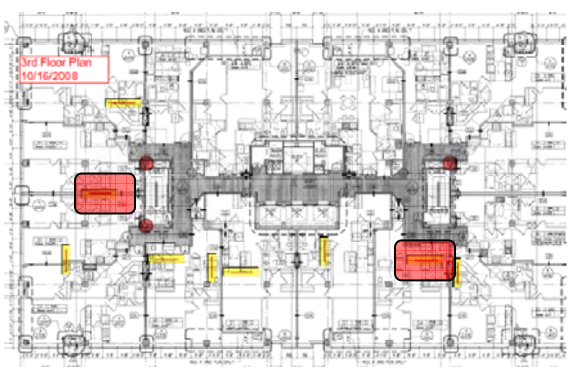

Figure 38 Marginal areas of reinforcement on 3rd floor

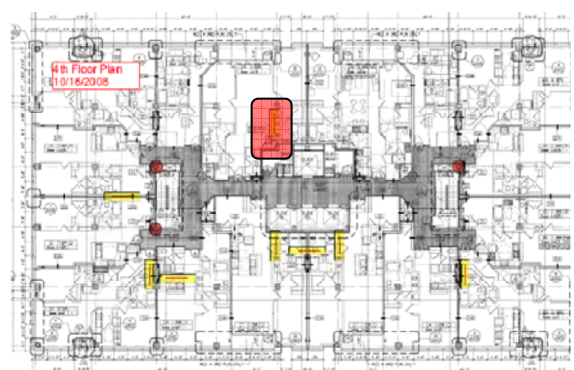

Figure 37 Marginal areas of reinforcement on 4th floor

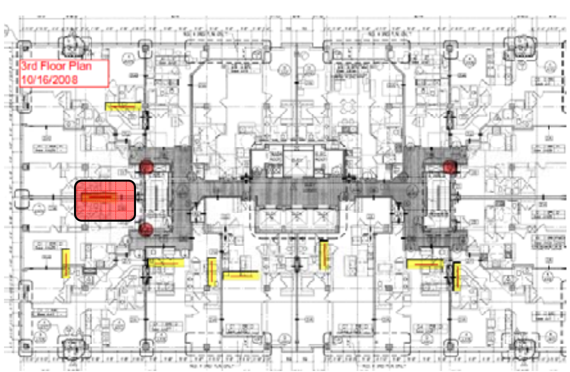

Figure 36 Marginal areas of reinforcement on 5th floor

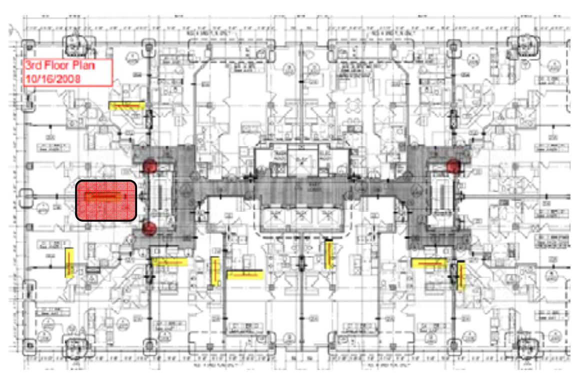

Figure 35 Marginal areas of reinforcement of 6th floor

Summary

In summary it can be easily seen the constructability issue with the slab penetrations in terms of cost and schedule. However, through the brief structural analysis, it can be determined prior to execution, how many bars can be cut, thus allowing for some manipulation to avoid the need for the costly structural reinforcing. While a more detailed analysis was done by the structural engineer, the spreadsheet used allows for rough numbers to be provided during a crucial time of the project, preconstruction.

However, given the limited ability for the MEP designers to move risers and shafts, the result may still require reinforcing, but the information to attempt to avoid it will at least be available. By knowing the potential areas requiring CFRP, the contractor can postpone installation of systems in the vicinity until the installation and fireproofing of the CRFP is complete.

Issues with the MEP systems may also arise by combining risers or using slab cuts rather than individual risers. For combining, there is an issue of testing and inspecting the pipe. Each vertical pipe has to be tested at every level using water under pressure. If a multitude of riser pipes were located together, the middle pipes would require testing first before those on the outside could be installed. This could have a drastic effect on the schedule. Also in terms of serviceability, if an interior pipe leaked or needed replaced, all outside pipes would require disassembly. In terms of support for the risers, all pipes need support horizontally at least every 2 floors. If multiple risers are located together a custom fabricated support bracket would be needed. Furthermore, by combining risers, the pressure required increase, therefore the potential to blow out the horizontal piping runs to the units becomes an issue.

Overall the structural analysis would be a great step to take in the preconstruction period, thus eliminating the do first, check second and moving more towards a check first, do, then evaluate. This allows for adjustments to be made during the process rather than dealing with surprises as they appear. This analysis would help mitigate the risk associated with the renovation.

In terms of the marginal areas, if the MEP systems could be adjusted an estimated savings of $3,000 could be obtained in just material cost. This does not include the cost to survey or rework the area. In addition, other areas requiring that only 2 or 3 less bars be cut are numerous, but hard to locate within the structural engineers program. Also, if the risk was assessed in preconstruction the cost of rework could be greatly reduced as these areas would not have material in place requiring tear down and reinstallation. The cost savings is this area alone would be approximately $55,000.